ISSN 0228-7048

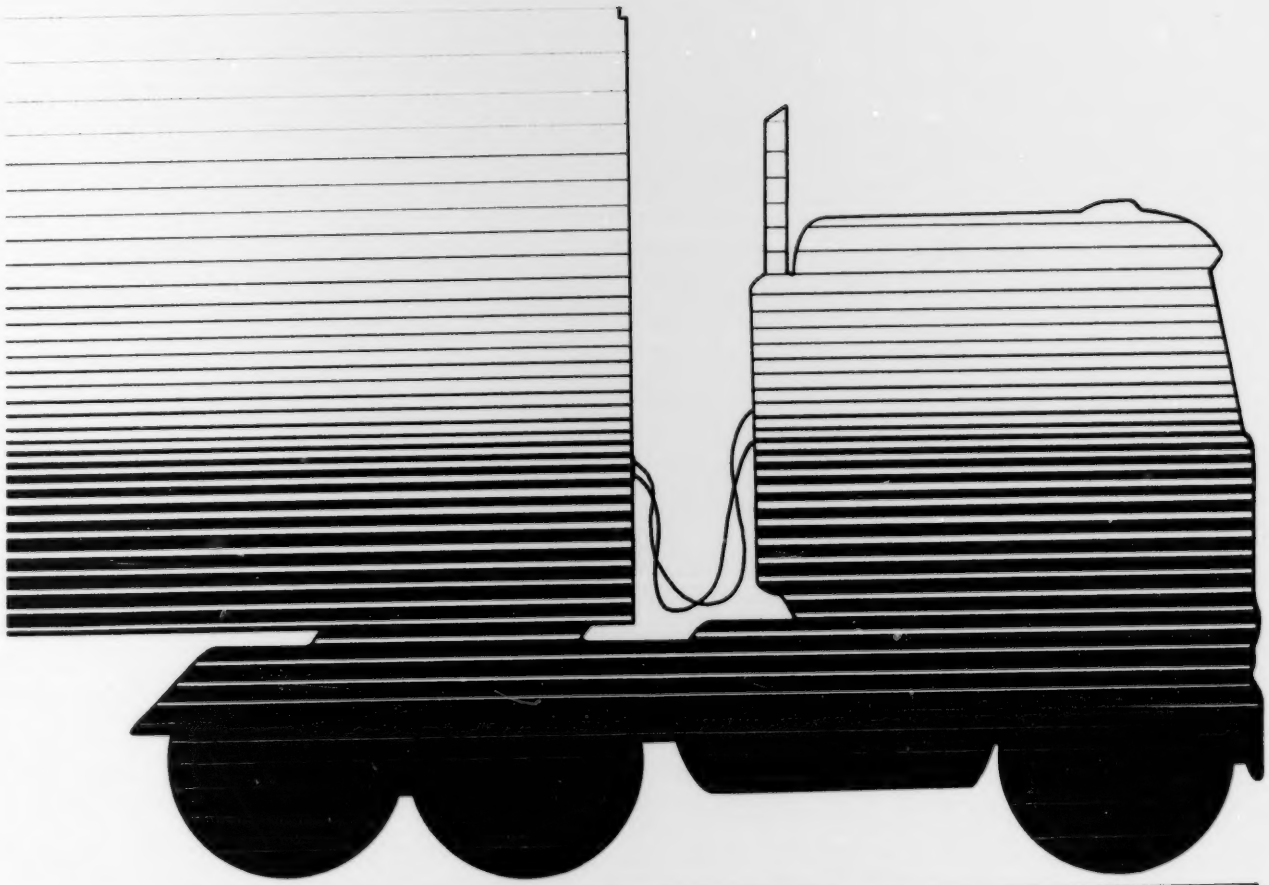
Ontario

Ministry of
Transportation and
Communications

Policy
Planning and
Research Division

The 1979 Survey of Commercial Vehicle Weights in Ontario

RR 230



Ontario

Ministry of
Transportation and
Communications

Policy
Planning and
Research Division

The 1979 Survey of Commercial Vehicle Weights in Ontario

P.F. Csagoly
Principal Research Officer

Z. Knobel
Senior Research Technician

Structural Research Group
Research and Development Branch

Published by
The Ontario Ministry of
Transportation and Communications
Hon. James W. Snow, Minister
H. F. Gilbert, Deputy Minister

Produced by Technology Transfer,
Research and Development Branch,
Policy Planning and Research Division.

Published without prejudice
as to the application of the findings.
Crown copyright reserved; however, this
document may be reproduce for non-commercial
purposes with attribution to the Ministry.

For additional copies write:
The Editor
Research and Development Branch
Ministry of Transportation and
Communications
1201 Wilson Avenue
Downsview, Ontario
M3M 1J8

First Printing, July, 1981

ISBN 0-7743-6045-3

Contents

Abstract		**1**
1/	**Introduction**	**1**
2/	**Previous Surveys**	**2**
	2.1/ 1967	2
	2.2/ 1971	4
	2.3/ 1975	6
3/	**The Ontario Highway Bridge Design (OHBD) Truck**	**9**
4/	**Statistical Analysis**	**18**
5/	**Conclusions**	**21**
6/	**References**	**22**

Abstract

Since 1967, the Ontario Ministry of Transportation and Communications has carried out regular load surveys at four-year intervals. The purpose of these surveys is to study the growth of vehicle weights, the impact of legislation upon the population of vehicles, and the effectiveness of law enforcement. In addition, the surveys were to ensure compatibility between actual vehicle weights and the loading highway bridges are designed for. This report describes the fourth such load survey.

1/ Introduction

The maximum permissible commercial vehicle weight in accordance with the regulations of the Ontario Highway Traffic Act [1] is 63 500 kg (140 000 lb.). The majority of bridges in the Ontario highway system were designed to the provisions of the AASHTO Specifications [2] which incorporate a 32 650 kg (72 000 lb.) vehicle for the design of highway structures. With the exception of the State of Michigan, the maximum permissible vehicle weight in the United States is limited to 36 300 kg (80 000 lb.).

The rather liberal weight limitations in Ontario are the result of extensive load surveys that have provided the research engineers of the Ministry of Transportation and Communications (MTC) with sufficiently accurate data regarding the actual weights, nature and distribution of commercial vehicles using the highway system. In addition, a continuous bridge testing program has identified hidden strength reserves in the majority of existing bridges designed to the AASHTO Specifications.

These liberal statutes were introduced in 1970 and after ten years' experience there is no evidence of failures or accelerated deterioration of Ontario's bridges due to heavier live loads. On the other hand, it is believed that the margin of safety of these bridges against failure has been reduced to a minimum below which, based on present day knowledge of structural behaviour, uncharted hazards lie for the professional engineer. In recognition of this fact, MTC is carrying out regular commercial vehicle surveys at 4-year intervals. The 1979 survey, described in this paper, is the fourth such survey.

2/Previous Surveys

2.1/ 1967

Structural research was established by MTC in 1967 in response to a request by the Ontario Trucking Association for higher permissible commercial vehicle weights. The first task of the structural research group was to establish the nature of then existing vehicles travelling the highway system. This included weighing axles and measuring interaxle spacings.

During the survey, taken in the Toronto area, 6763 vehicles were inspected. The data showed that the observed gross weights were usually close to allowable values but nominal maximum axle loads were frequently exceeded. Many vehicles were found to be too short for the loads carried, and their axles closely spaced. The latter can be detrimental to bridge decks and pavement structures. These findings were not entirely surprising since only gross weight restrictions had been enforced at that time.

Since load effects in bridge structures depend not only on the gross weight of the vehicle but also on the distribution of axle weights and interaxle spacings, it was felt that the increase (to 63 500 kg) sought by the industry could be attained at the price of axle weight and spacing control. For this, new methods of vehicle weight regulation, based on the concept of the Equivalent Base Length (B_M), were developed.

B_M is defined as an imaginary finite length on which the weight of an axle group sequence is uniformly distributed such that the maximum moments caused by this uniformly distributed load do not deviate unreasonably from the maximum moments due to the axle group proper. Derivation of the B_M equation is given elsewhere [see Reference 3].

$$B_M = \frac{4\sum_{1}^{N} |P_i x_i|}{\sum_{1}^{N} P_i} - \frac{2(N-1)}{bN}\left[\frac{\sum_{1}^{N} P_i x_i}{\sum_{1}^{N} P_i}\right]^2$$

where:

P_i = the ith load of the sequence,
x_i = distance between P_i and the axle closest to the centre of gravity of the sequence,
b = distance between the outside axles (base length),
N = number of axles in the sequence.

The second term in the B_M equation, especially for an odd number of axles, is usually very small and can be neglected for the sake of simplicity if so desired. B_M is a measure of the effectiveness of load distribution. If $B_M \leq b$, the distribution is poor — meaning that the load is concentrated on the mid part of the sequence.

The B_M concept permits a simple way of processing large volumes of vehicle data. Axle weights and spacings are fed into a computer which isolates valid sequences of axles and calculates pairs of $\Sigma P_i = W$ (weight of the sequence) and B_M values. The results are displayed by subdividing the B_M/W space into identical rectangles (bins) and when a pair of values is calculated, the number in the respective bin is increased by one. The advantage of this process is that all axle sequences (including the whole vehicle) producing maximum moments on any span of a bridge or component thereof can be incorporated. The display, as shown in Figure 1, may also be considered as a probability distribution surface identified at the centre points of the bins.

The Ontario Bridge Formula (OBF) is a sole function of B_M. In imperial units (kips and feet) the equation is:

$$W_M = 20 + 2.07\,B_M - 0.0071B_M^2$$

In SI metric units (kilograms and metres) the equation is:

$$W_M = 9072 + 3080B_M - 34.66B_M^2$$

The OBF was developed from a variety of considerations; two of them are illustrated in Figure 2. It can be seen that, with the exception of the single axle weight (W = 32 kips at B_M = 0), the OBF is following the AASHTO points reasonably close and it also satisfies the request by the trucking industry at B_M = 80 ft. This latter value was established by designing an optimal 8-axled vehicle within the then maximum allowable bumper-to-bumper vehicle length of 19.82 m (65 ft.). The OBF became law in Ontario on January 1, 1971.

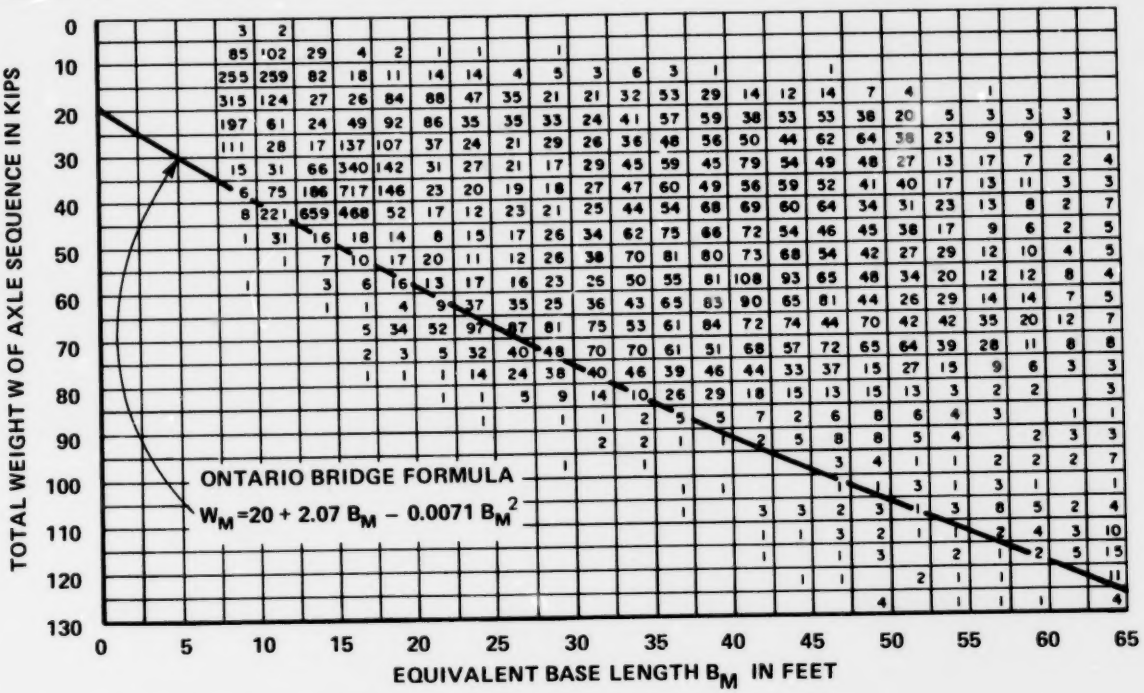
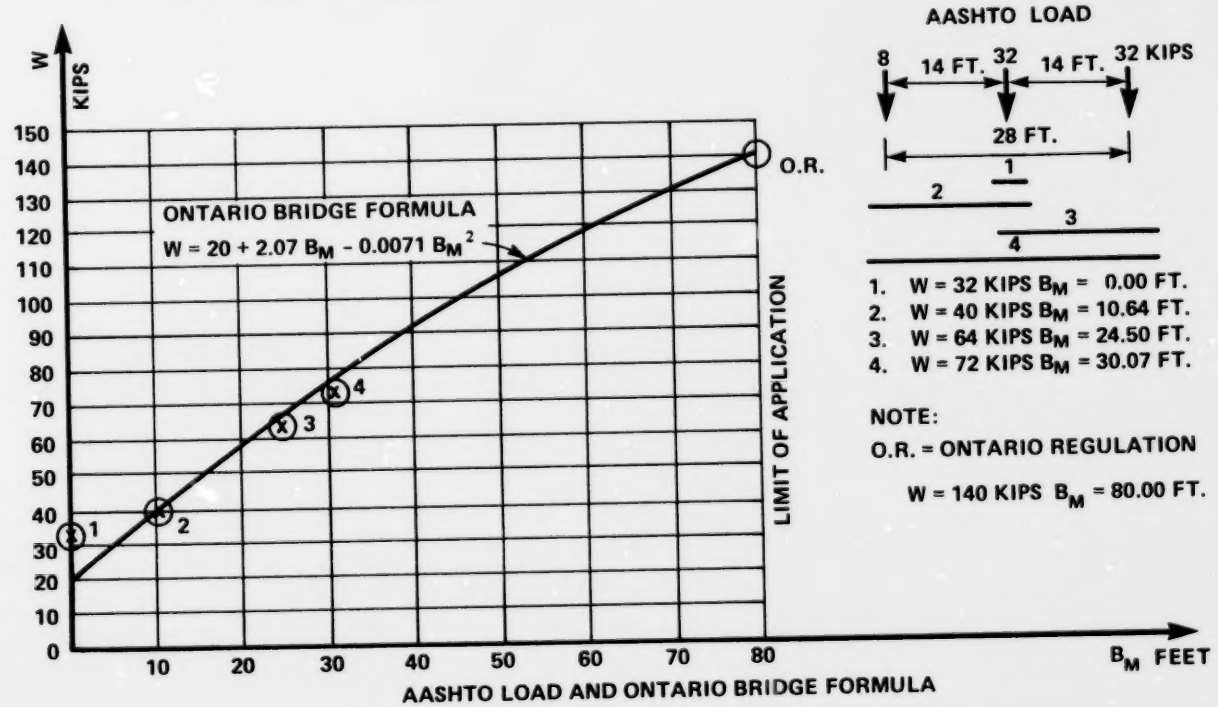


Figure 1/ W/B_M Plot Using 1967 Vehicle Survey Data

Figure 2/ AASHTO Design Vehicle Plot


W KIPS
ONTARIO BRIDGE FORMULA
$W = 20 + 2.07\ B_M - 0.0071\ B_M^2$
O.R.
LIMIT OF APPLICATION
B_M FEET
AASHTO LOAD AND ONTARIO BRIDGE FORMULA
AASHTO LOAD
8
14 FT.
32
14 FT.
32 KIPS
28 FT.
1. W = 32 KIPS B_M = 0.00 FT.
2. W = 40 KIPS B_M = 10.64 FT.
3. W = 64 KIPS B_M = 24.50 FT.
4. W = 72 KIPS B_M = 30.07 FT.
NOTE:
O.R. = ONTARIO REGULATION
W = 140 KIPS B_M = 80.00 FT.

2.2/1971

Although the Ontario Bridge Formula was only introduced at the beginning of 1971, the trucking industry, working closely with the officials of MTC, had spent about two years in preparing new vehicle designs before the date of introduction. The Ministry was, of course, interested in the immediate impact of the OBF upon the population of commercial vehicles and therefore ordered another survey.

The survey was carried out by weigh station attendants and it was essentially a by-product of normal station operations. It included only those vehicles which were stopped for alleged licence, traffic, weight/length, or other violations. It included only loaded vehicles but also covered special permit units. A total of 7292 vehicles were inspected and axle weight and interaxle data were collected.

The data were processed and displayed in a manner similar to those of the 1967 survey, except that the bins were made smaller (1 kip vs. 5 kips and 2 ft. vs. 5 ft.) as shown in Figure 3. The OBF is indicated by a broken line. It can be seen that, with the exception of a group of cases in the region of 8 ft. $\leqslant B_M \leqslant$ 14 ft., the excesses form a band of essentially constant width of 22.5 kips (10 206 kg). Thus, an upper bound curve, christened the Maximum Observed Load (MOL), was obtained for possible future use as a design load.

In imperial units:

$$MOL = 42.5 + 2.07B_M - 0.0071B_M^2$$

In metric units:

$$MOL = 19\,278 + 3080B_M - 34.66B_M^2$$

The circled area in the region of 8 ft. $\leqslant B_M \leqslant$ 14 ft. relates to sequences such as dual and triple axle units of special permit vehicles. The identification of these units signalled the beginning of work towards creating guidelines for the control of special permit vehicles. There are six other individual cases, marked by small circles, where the MOL curve has been exceeded. As the data of this survey were accidently destroyed, it is not possible to identify these cases as either regular or special permit units.

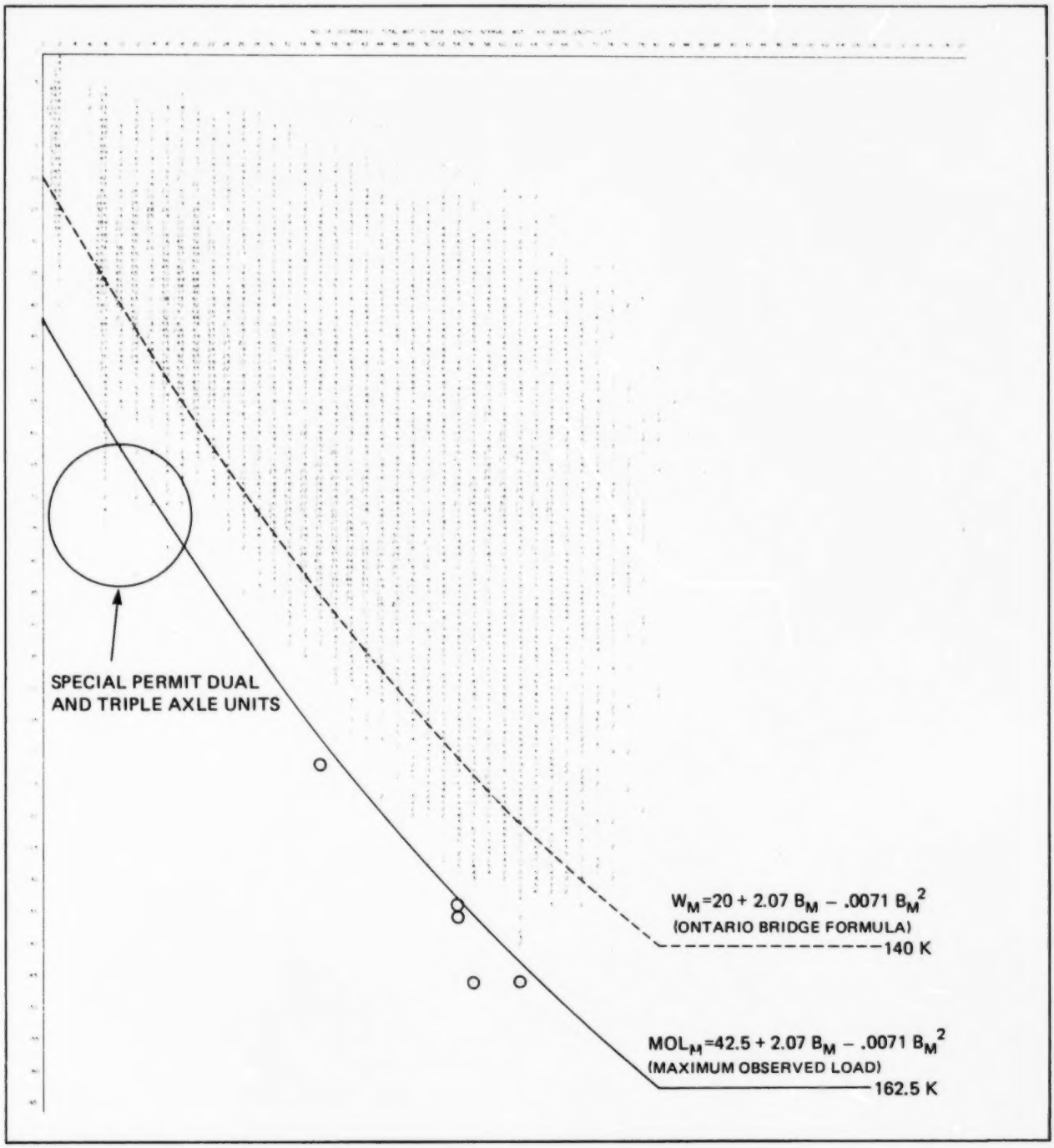


Figure 3/ 1971 Vehicle Survey Data Plot

2.3/ 1975

The purpose of the 1975 survey was threefold, namely, to study: 1/ the growth of vehicle weights, 2/ the impact of the 1970 legislation upon the population of commercial vehicles, and 3/ the effectiveness of then existing methods of law enforcement. The actual work had been preceded by a pilot study to provide the basis for a province-wide statistical distribution of the data to be collected.

The pilot study included monitoring truck traffic at 47 operating truck inspection stations. In order to avoid bias, this was done when the stations were closed. Canon F-1 cameras were equipped with split lenses such that, in addition to a colour picture of the vehicle, the location, date, arrival time, direction and speed of the vehicle were also recorded. Altogether, 14 400 pictures were taken and evaluated. The results were used to establish the number of loaded vehicles of given types to be recorded at an inspection station for the main survey.

In the main survey, a total of 9864 vehicles were surveyed. Of these, 9250 carried regular permits and 614 special permits. The procedure and outcome of the survey is given in Reference 4. Figure 4 is the W/B_M display of all regular permit vehicles observed, while Figure 5 illustrates the same for those travelling under special permit. Both figures indicate the OBF and MOL curves as well. It can be seen that, with a very few exceptions, regular permit vehicles seem to toe the MOL curve – a situation that had not appreciably changed since 1971. On the other hand, a considerable number of special permit vehicles break the MOL curve in two areas circled in Figure 5. Area A belongs to dual and triple axle units while area B is associated with gross vehicle weights. This data indicated that special permit vehicles in 1975 were travelling in the province without weight control for any practical purposes – a very serious concern.

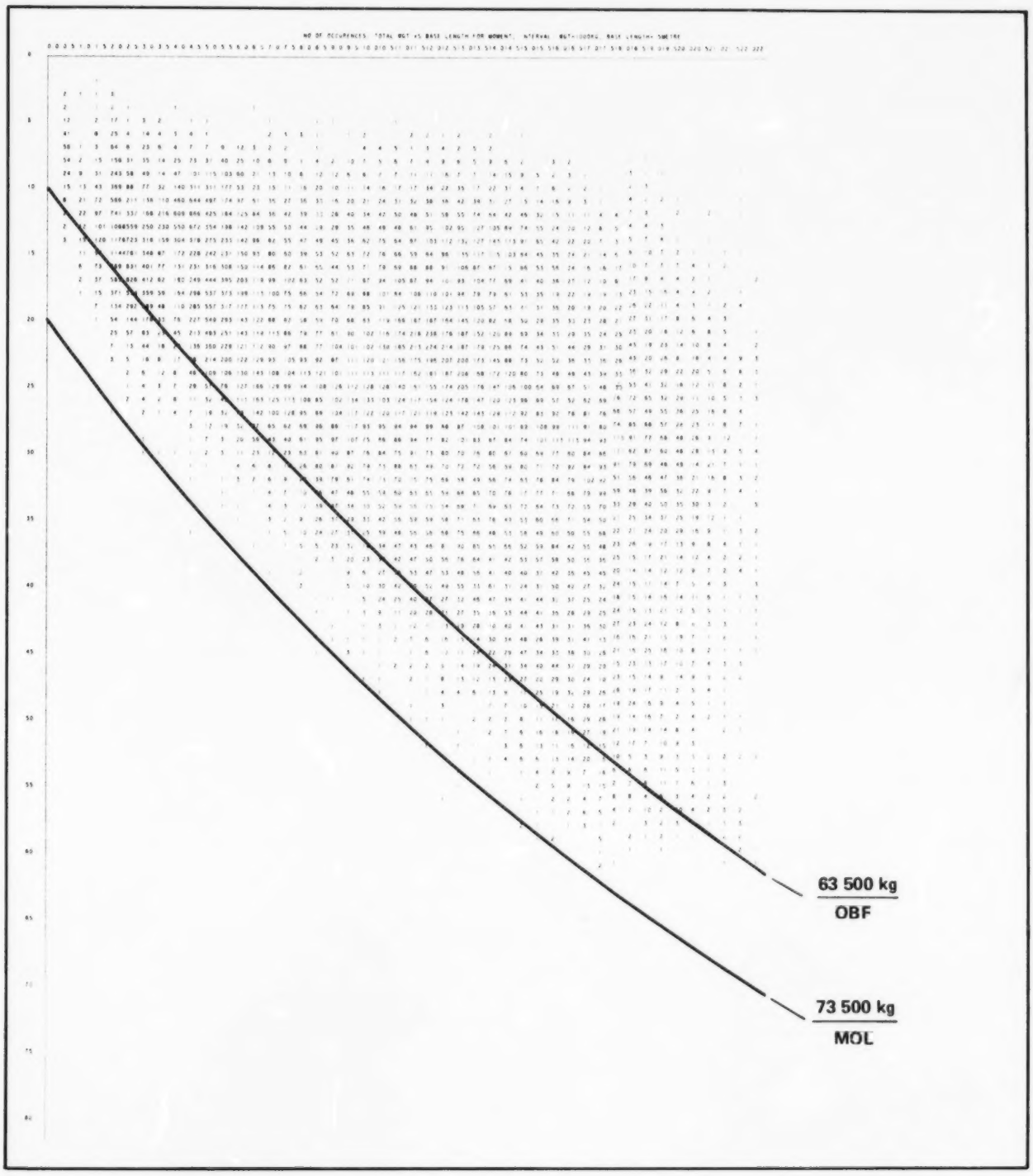


Figure 4/ Regular Permit Vehicles (9250) Surveyed in 1975

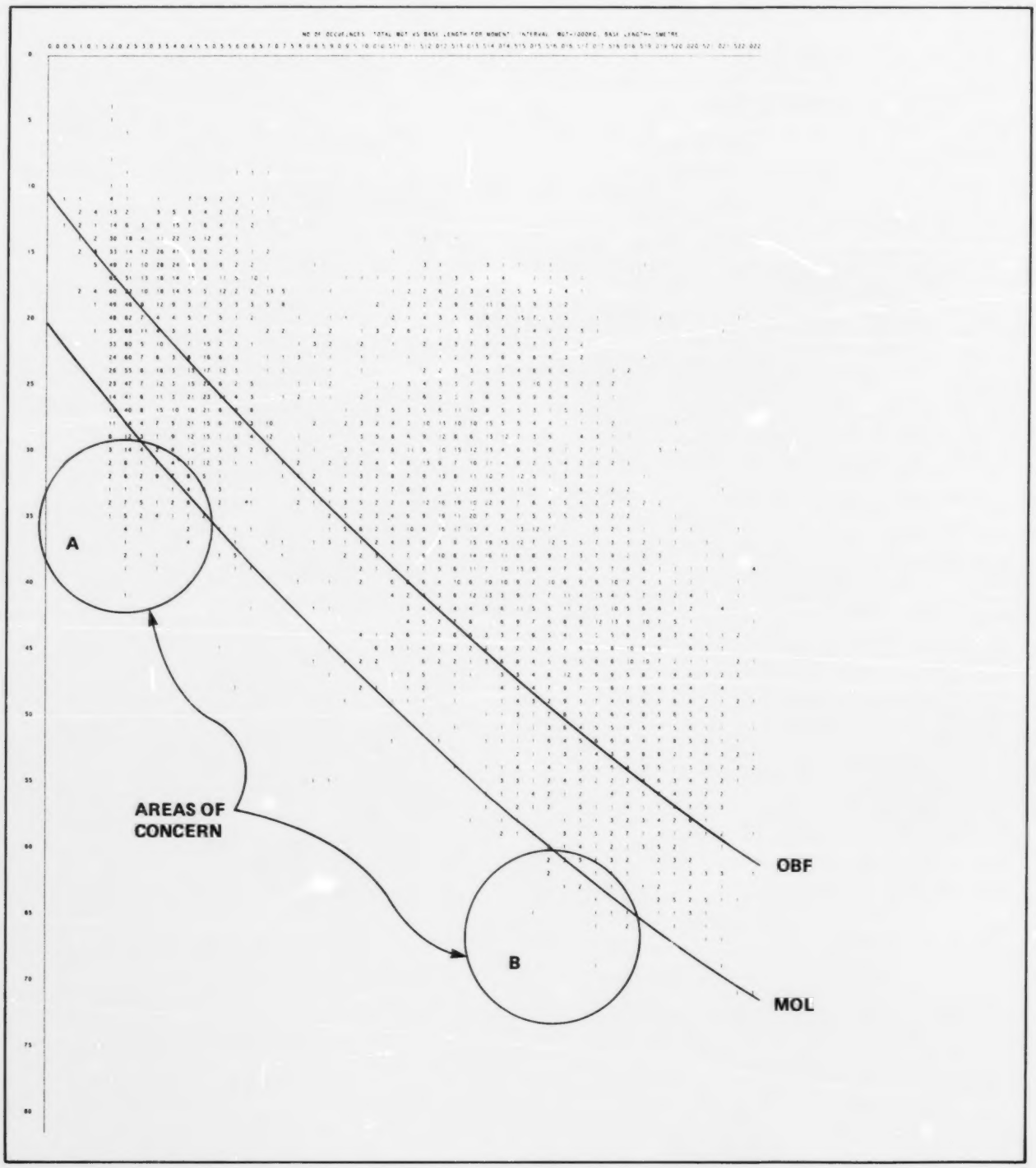


Figure 5/ Special Permit Vehicles (614) Surveyed in 1975

3/ The Ontario Highway Bridge Design (OHBD) Truck

The Ministry began writing the Ontario Highway Bridge Design Code in 1976. At about the same time, a major study was initiated regarding regional jurisdiction over issuing special permits and implementing weight control guidelines that had been tentatively adopted by MTC in 1974 as the probable basis of its future policy. Among other things, the guidelines stipulated that the weight of special permit vehicles and subconfigurations thereof should not exceed the MOL curve unless certain particular criteria, set by MTC for each individual case, are satisfied. On this assumption, the MOL curve had been adopted as the basis of the design truck for the Ontario Bridge Design Code.

The format of a design load is somewhat arbitrary and a variety of proposals for it were entertained. Selected was an imaginary 5-axled vehicle of 700 kN (157 375 lb. or 71 384 kg) weight and 18.0 m (59.0 ft.) base length. This Ontario Highway Bridge Design Truck is illustrated in Figure 6 together with its valid subconfigurations, ranging from A to H.

Figure 6/ OHBD Truck and its Valid Subconfigurations

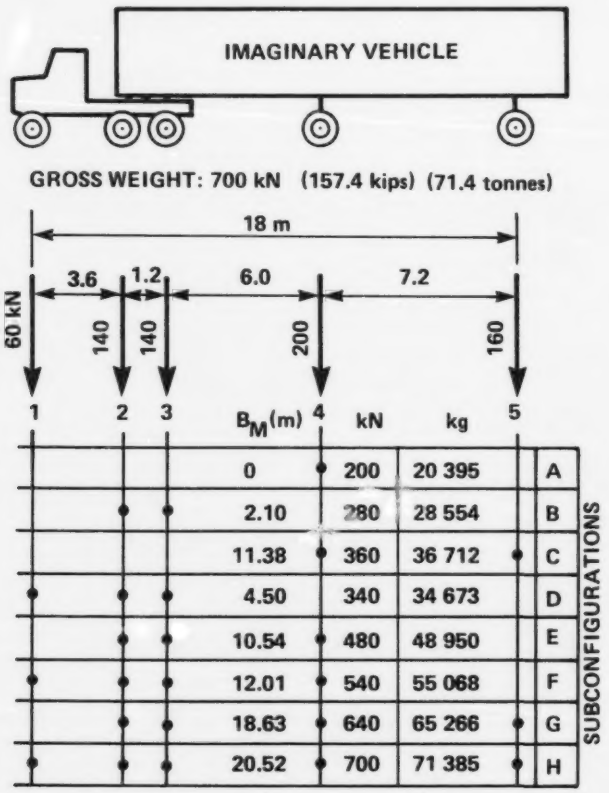
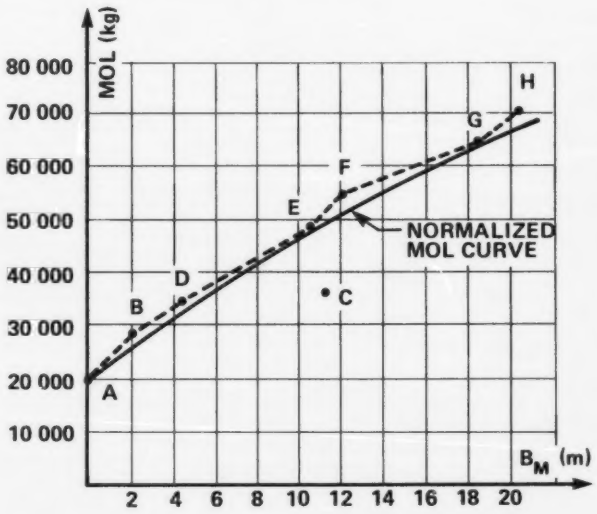


Figure 7 compares the MOL curve with the W/B_M plot of the various subconfigurations and the whole vehicle (H) of the OHBD Truck.

It can be seen that with the exception of "C", which consists of two single axles a large distance apart, all points and their interconnecting straight lines are slightly above the MOL curve. The fact that "C" falls well below the curve is of no real concern as far as design is concerned since "E" and "F" are located in the immediate vicinity.

The MOL curve shown in Figure 7 is somewhat

Figure 7/ Relationship Between MOL Curve and OHBD Truck



different from the one given earlier. It has been normalized in conjunction with the issue of weight regulating tables in the 1978 Highway Traffic Act.
In metric units (kg):

$$MOL = 20\,000 + 3000B_M - 32.50B_M^2$$

The difference between the MOL and OBF has been set to be 10 000 kg. Accordingly:

$$W(OBF) = 10\,000 + 3000B_M - 32.50B_M^2$$

In imperial units (kips) this translates into:

$$W(OBF) = 22 + 2.02B_M - 0.0067B_M^2$$

The above-mentioned regulating tables are a close approximation of this metric OBF formula.

3.1/ The 1979 Survey

The refined and statistically-based 1975 survey had cost upwards of $100 000 – an expenditure the 1979 budget of MTC could not bear. In any case, the difference between the results of the 1971 and 1975 surveys was so insignificant as not to justify another statistically based undertaking at this time. Therefore, a different approach was taken. . .

In Ontario, weight violations are recorded at the inspection stations by filling out a standard form called the Highway Traffic Act Weight Report (HTAWR) used for the purpose of legal action. The MTC Regional Operations Division, which operates the stations, collects on the average about 1000 HTWAR per month. As these reports are collected on a province-wide basis, they can be considered statistically significant. It was decided that they could be utilized for the 1979 survey.

Between February and July, 1979, a shade over 5000 reports were collected from 53 operating stations. A number of these were rejected due to poor legibility, mistakes and missing information, leaving a net total of 4901 valid reports. Of these, 4782 were of regular permits and 119 were of special permit cases.

From these reports, the following information was extracted and stored on disc at Downsview under the code name "TCSR.AATRS79. SURVEY. DATA":

1/ Sequence number of truck inspection stations (Table 1).
2/ Month and year, when the violation occurred.
3/ Type of vehicle (Table 2).
4/ Configuration of vehicle (Figure 8).
5/ Axle weights in units of 100 kg.
6/ Interaxle distances in metres.
7/ Vehicle sequence number from 1 to 4901.

There is a large variety of ways these data can be presented. Table 3 indicates the distribution of vehicles according to the number of axles. It can be seen that 1748 trucks, or 35.7% of the population, with 5 axles are dominating the field. A considerable part of this segment is believed (although not recorded) to be from outside the Province of Ontario, primarily from the United States where due to the 80 000 lb. weight limit, the 3S2 type (i.e., 3-axled tractor with a 2-axle semi-trailer) is the top of the line. In all, 1653 vehicles, or 33.7%, had 6 axles or more. These vehicles came into being almost exclusively as a result of the Ontario Bridge Formula.

Table 4 displays the ten heaviest axles for each axle location of all vehicles involved. It is interesting to note that the most extensively overloaded axles

	Sequence Number	Name	Location Hwy. No.	No. of Vehicles Surveyed
Central Region	01	Bowmanville	401	155
	02	Cooksville	5	19
	03	Fort Erie (audit)	QEW	0
	04	Fruitland	QEW	111
	05	King	400	235
	06	Lorne Park	QEW	185
	07	Oakville	QEW	390
	08	Streetsville North	401	118
	09	Streetsville South	401	277
	10	Victoria (audit)	10	78
	11	Whitby	401	495
	12	Winona	QEW	68
	13	Woodbridge	400	134
	58	Cambridge	97	2
	59	Kitchener	7	17
	60	Guelph	6	5
	61	Listowel	23	8
	65	Whitchurch-Stouffville	48	5
Northern Region	14	Cochrane	11	26
	15	Gravenhurst East	11	0
	16	Gravenhurst West	11	50
	17	Hearst (audit)	11	12
	18	Huntsville (audit)	60	
	19	Kapuskasing (audit)	11	
	20	New Liskeard (audit)	11	25
	21	North Bay South	11	51
	22	North Bay West	17	44
	23	Parry Sound	69	54
	24	Sault Ste. Marie	17	2
	25	Spragge	17	88
	63	Owen Sound	24	4
Northwestern Region	26	Dryden	17	0
	27	Fort Francis (audit)	11	2
	28	Keewatin	17	2
	29	Nipigon (audit)		34
	30	Thunder Bay North	102	3
	31	Thunder Bay South	11	9
	32	Vermilion Bay (audit)	17	0
Southwestern Region	33	Chatham	2	11
	34	Eastonville (audit)	3	0
	35	Holmesville (audit)	8	6
	36	Putnam South	401	342
	37	Putnam North	401	398
	38	Windsor South	401	124
	39	Windsor North	401	89
	40	Wyoming	7	80
	54	Sarnia North	402	100
	55	Sarnia South	402	176
	61	London	401	10
Eastern Region	41	Alfred	17	5
	42	Gananoque North	401	193
	43	Gananoque South	401	198
	44	Glen Tay	7	24
	45	Lancaster	401	109
	46	Curry Hill	401	280
	47	Pembroke	17	21
	48	Prescott North	401	4
	49	Prescott South	401	0
	50	Long Lac (audit)	11	0
	51	Red Lake (audit)	105	0
	52	Smooth Rock Falls (audit)	11	0
	53	Bismark	20	0
	56	Hawkesbury	17	8
	57	Bancroft	62	8
	64	Lindsay	7	1

Table 1/ Truck Inspection Stations in the Province of Ontario

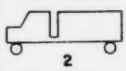
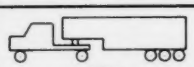
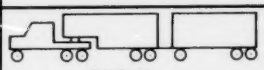
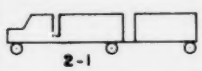
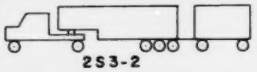
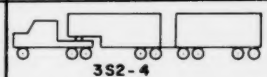
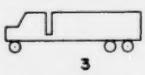
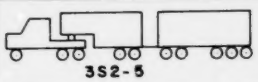
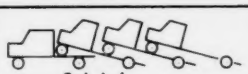
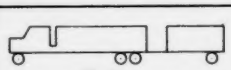
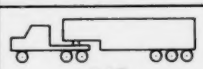
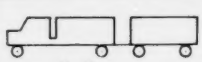
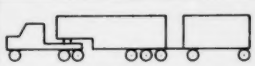
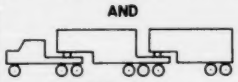
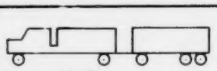
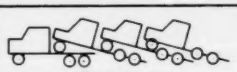
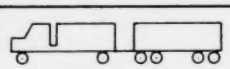
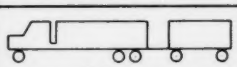
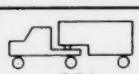
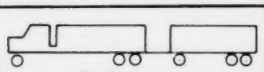
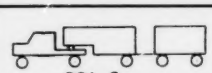
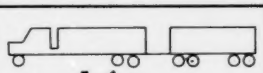
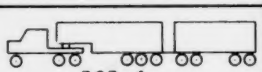
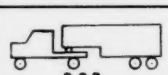
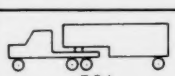
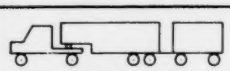
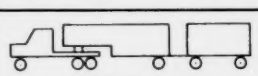
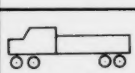
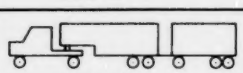
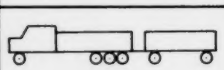
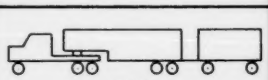
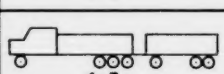
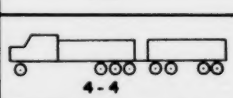
CODE No.	VEHICLE CONFIGURATIONS	No. 1979 SURVEY	CODE No.	VEHICLE CONFIGURATIONS	No. 1979 SURVEY	CODE No.	VEHICLE CONFIGURATIONS	No. 1979 SURVEY
1	 2	618	13	 2S3	19	26	 3S2-3	128
2	 2-1	18	14	 2S3-2		27	 3S2-4	9
3	2-1-1	13	15	 3	382	28	 3S2-5	
4	 2-1-1-1		16	 3-1		29	 3S3	1183
5	 2-2	23	17	3-1-1	3	30	 AND  3S3-2	27
6	 2-3	11	18	 3-1-1-1				
7	 2-4		19	 3-2	8	31	AND 3S3-3	9
8	 2S1	15	20	 3-3	8			
9	 2S1-2	7	21	 3-4	8	32	 3S3-4	4
10	 2S2	387	22	 3S1	2	33	3S4	135
11	 2S2-2		23	 3S1-2	2	34	 4	25
12	 2S2-3		24	3S2	1682	35	 4-2	3
			25	 AND 3S2-2	165	36	 4-3	5
						37	 4-4	2

Figure 8/ Commercial Vehicle Configurations

Type of Truck			
00/ No information	06/ Float	12/ Pole-truck	18/ Line truck (hydro)
01/ Van	07/ Car carrier	13/ Towing Truck	19/ Sander – MTC
02/ Stake	08/ Mobile crane	14/ Sander	20/ Plow – MTC
03/ Flat	09/ Pick-up	15/ Tractor bob-tail	21/ Horse van
04/ Dump	10/ Cement mixer	16/ Garbage truck	22/ Fire truck
05/ Tank	11/ School bus	17/ Panel truck	

Table 2/ Type of Trucks Identified

Number of Axles	Number of Trucks	Percent
2	628	12.8
3	431	8.8
4	441	9.0
5	1 748	35.7
6	1 174	23.9
7	302	6.2
8	158	3.2
9	15	0.3
10	4	0.1
TOTAL: 4 901 trucks		100.0

Table 3/ Distribution of Vehicles According to Number of Axles

Rank	Steering	2nd	3rd	4th	5th	6th	7th	8th	9th	10th
1	11.0	16.0	14.8	17.1	15.8	14.9	13.3	10.9	8.8	7.2
2	10.8	15.8	13.8	15.8	15.5	13.3	12.3	10.5	8.2	7.1
3	10.4	15.4	13.8	15.6	15.5	13.2	11.5	10.4	7.5	6.7
4	10.3	15.1	13.6	15.5	14.9	12.8	11.3	10.3	7.3	
5	10.0	15.1	13.6	15.5	14.7	12.8	11.2	10.3	7.3	
6	9.9	15.0	13.6	14.7	14.5	12.8	11.2	10.3	7.2	
7	9.6	14.9	13.5	14.5	14.3	12.6	11.1	10.2	7.1	
8	9.4	14.8	13.3	14.4	14.1	12.5	11.0	9.8	6.8	
9	9.4	14.7	13.3	14.3	13.7	12.5	11.0	9.1	6.8	
10	9.4	14.5	13.3	14.1	13.5	12.4	11.0	9.1	6.7	

Note: HTA limit on single axle is 10 000 kg (10.0 x 1000)

Table 4/ Ten Heaviest Single Axle Weights (1000 kg)

were found to be the 4th and 5th ones. Further investigation revealed that the majority of these belong to 5-axled vehicles indicating an understandable tendency of the users to over-utilize outdated (from the Ontario point of view) equipment they have on hand.

Table 5 depicts the ten heaviest tandem weights as a function of interaxle spacings. Also shown are Highway Traffic Act permissible weights and average percentile violations. With the exception of the last column (which includes non-mechanically connected consecutive axles), there appears to be a remarkable tendency reinforcing the observation made in conjunction with Table 4. Average violations of 57.5 and 59.8% between 120 and 140 cm interaxle spacings (measurements still prevailing outside Ontario) can be noted. Again, the majority of these violations involved 5-axled vehicles.

Table 6 illustrates the same for triple axles. These units almost exclusively belong to vehicle combinations having six axles or more. The calculated average of violations is of interest.

For 240 cm $\leq$ b $\leq$ 280 cm, dimensions, associated with the units built before the introduction of the Ontario Bridge Formula, an average violation of 35.6% was obtained.

For b>300 cm, however, the violations are reasonably small and evenly distributed – maximum, minimum and average being 27.7%, 4.5% and 17.6%, respectively.

The Ontario Bridge Formula grades the permissible weight in accordance with the base length and provides a tool for the equipment designer to take best advantage of the statutes. The observed situation in the region of b>300 cm is the first concrete proof that economic incentives, properly defined and explained, can lead to low levels of violations that are of little or no concern from the technical and engineering points of view.

The 1979 survey data were also plotted in a way similar to those of the 1967, 1971 and 1975 surveys. Figure 9 illustrates the distribution of 4782 regular permit trucks over the W/B_M space subdivided into 1000 kg x 0.5 m bins. Altogether, 13 vehicles exceeded the MOL curve. (It may be noted that several sub-configurations of a vehicle may be registered by this process on the W/B_M chart. Hence, the total number of occurrences is greater than 13.) Seven of these vehicles exceeding the curve were recorded in Southern Ontario, all carrying heavy machinery. These violations, although not excusable, reflect the operational difficulties in positioning heavy machinery on the vehicle to obtain a proper distribution of the payload among the axles.

The other six vehicles exceeding the MOL curve

Table 5/ Ten Heaviest Dual Axle Weights (1000 kg)

Rank	Interaxle Spacing in cm: 60-120	121-130	131-140	141-150	151-160	161-170	171-180	larger than 180
1	23.0	31.6	31.0	29.6	27.6	31.0	23.4	27.2
2	23.0	27.0	29.0	29.4	27.2	24.8	22.4	26.6
3	23.0	26.6	28.6	27.6	27.0	23.2	22.4	26.0
4	22.3	26.4	28.2	26.6	25.8	22.8	22.2	25.6
5	21.4	26.2	27.4	25.2	25.2	22.6	22.2	25.6
6	20.8	26.0	27.2	25.0	25.2	22.6	22.2	25.6
7	20.8	25.4	26.6	25.0	25.0	22.6	22.0	25.0
8	20.2	25.4	25.8	24.4	25.0	21.8	22.0	25.0
9	19.8	25.2	25.6	24.4	24.8	21.6	21.6	25.0
10	19.8	24.8	25.4	23.6	24.6	21.0	21.6	25.0
Permissible Weights	15.4	16.8	17.2	17.5	17.9	18.3	18.7	19.1
Average Percentile Violations	39.0	57.5	59.8	49.0	43.8	27.9	18.7	34.4

were stopped in the Northern Regions. All were carrying logs. It must be noted that the Highway Traffic Act (Section 75) allows a 10% increase above the OBF values for vehicles transporting raw forest products during the period of freeze-up. All these vehicles were caught in March which is, of course, within this period. At the 63 500 kg level, the 10% allowance reduces the 10 000 kg buffer between the OBF and MOL curves to 3650 kg, or 5.2% gross weight. Considering the highly variable nature of water content of logs alone, MOL violations are understandable – although, again they are not excusable.

Figure 10 displays the distribution of 119 special permit vehicles over the W/B_M space. There are seven individual violations on this chart, caused by six vehicles, the majority of them carrying heavy machinery. The MOL violations are in the region of $2.0\ m \leq B_M \leq 3.5\ m$, i.e., they are associated with dual and triple axle units. These violations are believed to be the result of the tentative nature of the current policy of MTC by which no control is being exercised regarding axle unit weights.

The number of vehicles violating the MOL curve appear to be entirely out of proportion with regard to the total number of vehicles monitored in the five regions of MTC. The relevant figures are shown in Table 7. It can be seen that for the first four regions MOL-violations range from 0.15 to 0.56%, while the North Western Region stands out with 8.00%. As the total number of vehicles recorded in North Western Region was extremely low (50) in comparison with the other regions, it is difficult to attach any

Table 7/ Regional Distribution of MOL Violations

Region	Number of Vehicles Monitored	Number of MOL Violations	Percentage of MOL Violations
Central	2308	9	0.39
Northern	356	2	0.56
Eastern	851	2	0.24
South Western	1336	2	0.15
North Western	50	4	8.00
Total	4801	19	0.40

Table 6/ Ten Heaviest Triple Axle Weights (1000 kg)

Rank	Base Lengths in cm: to 240	241-280	281-300	301-320	321-340	341-360	361-380	381-400	401-420	421-440	441-460	461-480	Greater than 480
1	22.2	35.4	25.9	31.5	30.5	29.4	32.7	31.8	32.2	33.5	33.5	32.4	34.4
2	19.2	30.6	24.3	29.7	30.5	27.6	32.6	31.8	32.0	33.2	32.1	32.3	34.3
3	18.3	30.6	23.9	28.2	28.2	27.0	31.8	31.3	30.8	32.4	31.9	31.7	33.6
4	17.4	28.8	22.9	26.5	27.7	26.9	31.3	31.1	30.7	32.4	31.9	31.0	33.4
5	14.4	27.6	22.2	26.1	26.7	24.3	31.3	30.0	30.7	32.3	31.2	30.9	33.2
6	12.0	27.3	21.3	26.1	25.5	24.2	31.1	30.5	30.6	32.1	31.0	30.9	33.2
7	11.7	27.3	19.0	26.1	25.2	23.5	30.9	30.4	30.6	31.9	31.0	30.5	33.1
8	9.9	27.3	18.3	26.0	25.2	22.3	30.3	30.0	30.5	31.0	31.0	30.3	32.9
9	8.4	27.0	18.0	25.5	25.2	22.0	30.0	30.0	30.4	30.8	30.7	29.1	32.8
10	7.8	27.0	18.0	25.5	26.4	21.6	29.8	29.7	30.2	30.3	30.6	29.0	32.7
Permissible Weights	19.5	21.3	21.7	22.4	23.1	23.8	24.4	25.1	25.8	26.5	27.2	27.9	28.6
Average Percentile Violations	NONE	35.6	NONE	21.1	17.2	4.5	27.7	22.5	19.7	20.7	15.8	10.4	16.6

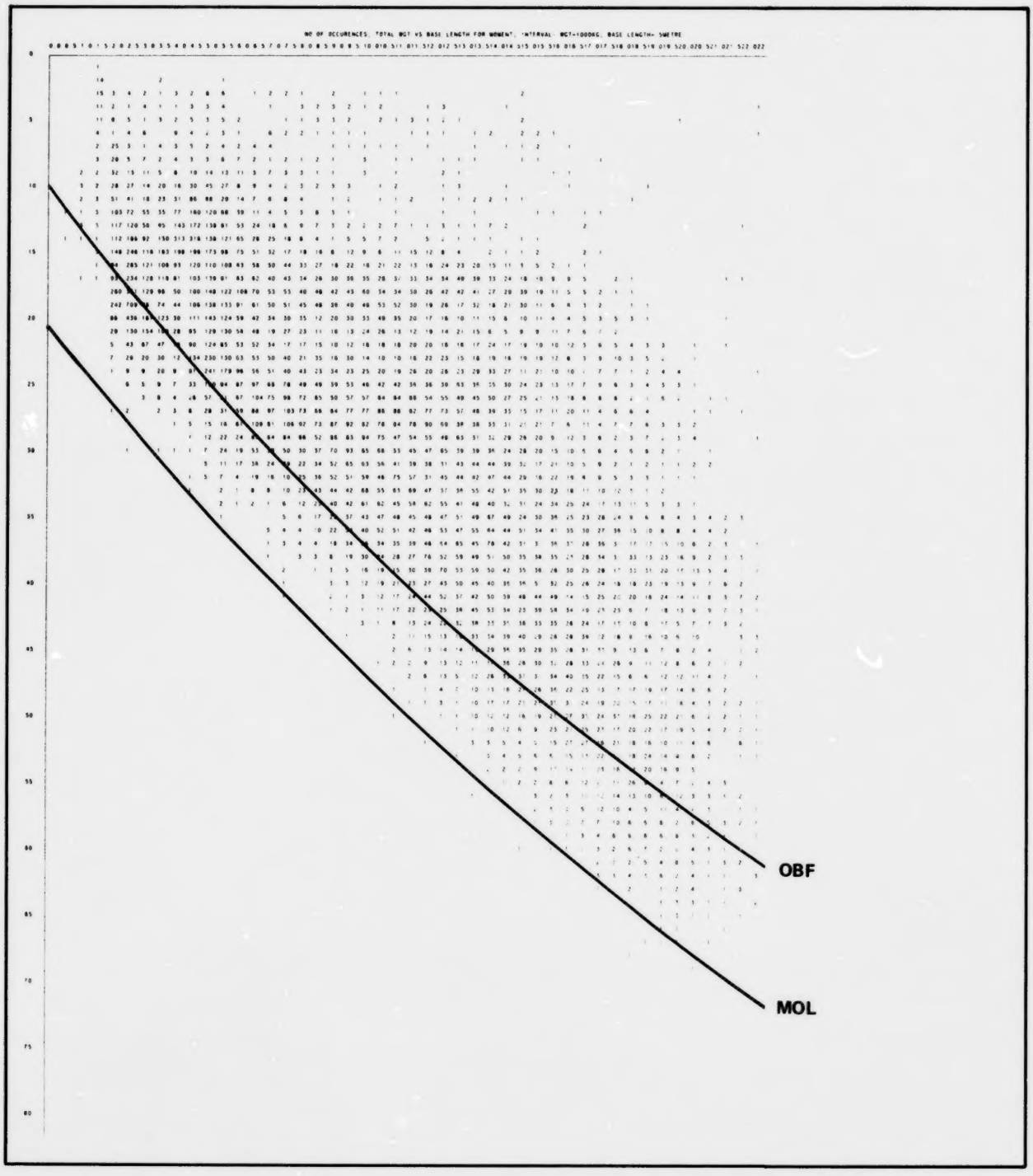


Figure 9/ Regular Permit Vehicles (4 782) Surveyed in 1979

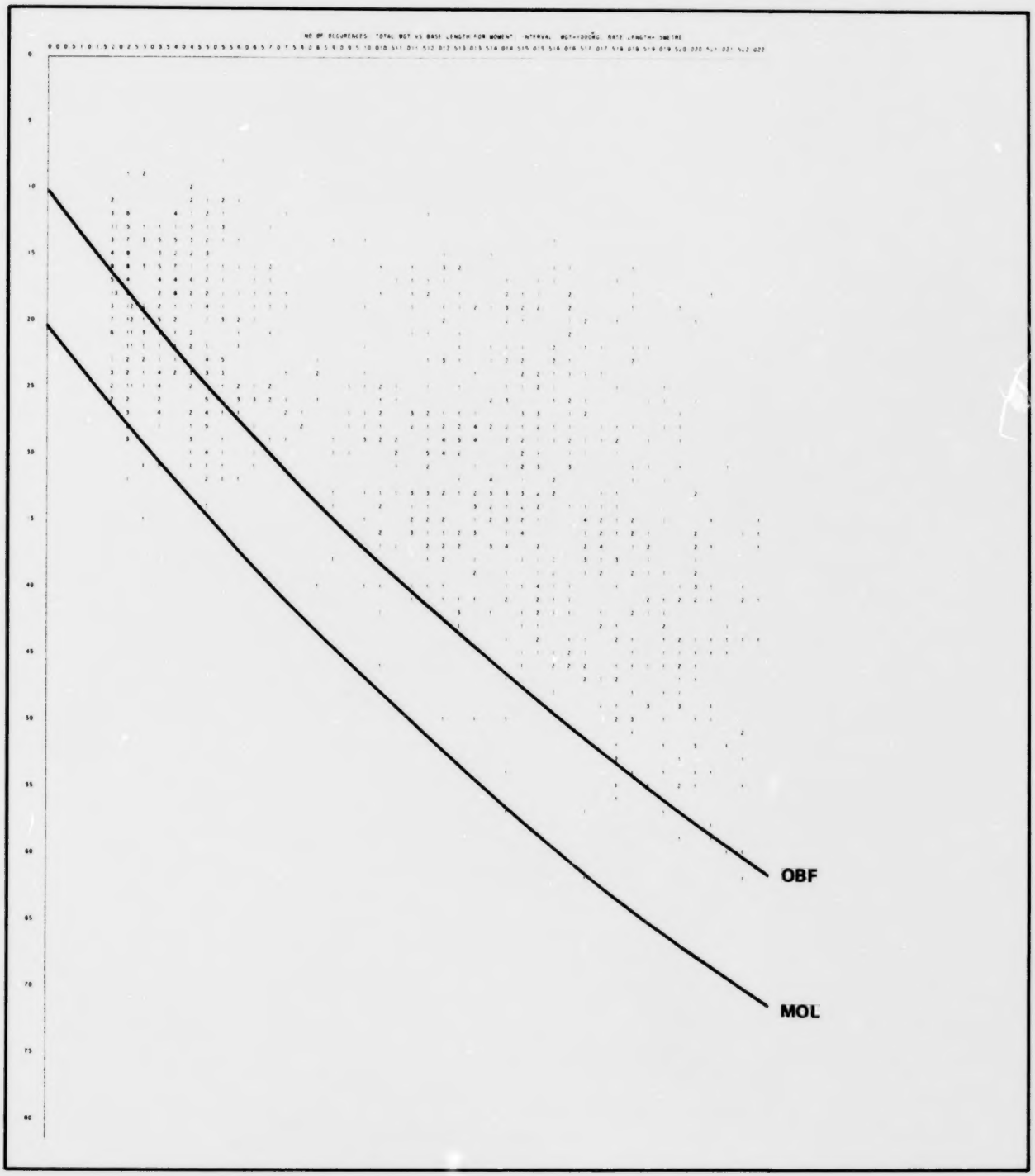


Figure 10/ Special Permit Vehicles (119) Surveyed in 1979

significance to the 8% (4 vehicles) value obtained. It has been learned from operational sources that during the period of survey the majority of scales in North Western Region were closed for repairs and for investigating alleged errors in weighing.

The Ontario highway load system is based on the 10 000 kg buffer between the OBF and MOL curves. The OBF curve is the legal limit and it is supposed to be used by law enforcement to ensure that the MOL curve, the engineering limit, is not exceeded. The fact that 19 vehicles were found to have exceeded the MOL curve is, therefore, an engineering concern.

The Ontario Highway Bridge Design Code is based on limit states principles which, in turn, assume the availability of statistical data regarding loads and the behaviour of structural materials. There are two types of limit states, namely *serviceability* and *ultimate*. Serviceability limit states are associated with the mean of *all* loaded vehicles traversing the highways, therefore with the mean of the population. The 1979 survey data, that are valid only for cases exceeding the OBF curve, cannot be used for this purpose. In order to illustrate the statistical use of the W/B_M display, the 1975 data will be utilized.

Serviceability limit states Type I of the 1979 Code relates exclusively to fatigue of structural metals. Having made use of a mixture of Canadian and American data, the load to be used in fatigue design of highway bridges is 80% of the OHBD Truck. Only one such truck is to be placed on the bridge at a time, but in governing position regarding the point of interest concerned. As the Code is being implemented, fatigue considerations are often found to control the design of steel bridges, therefore a review of the relevant provisions seems to be in order.

The W/B_M display of regular permit vehicles surveyed in 1975 (Figure 4) has been sliced at 2.5 m intervals. Each slice results in a probability distribution of weight W for a given value of B_M. One such distribution of B_M = 10.0 m is illustrated in Figure 11. It can be seen that the distribution is reasonably Gaussian – mean, standard deviation, and coefficient of variation were calculated to be 23.77 tonnes, 6.81 tonnes and 28.65%, respectively. The theo-

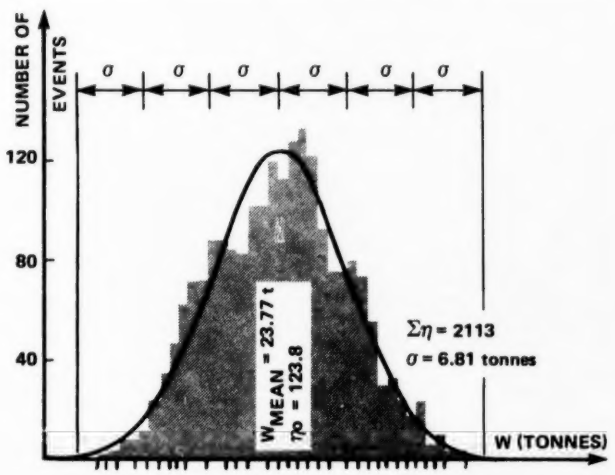


Figure 11/ Distribution of Weights for B_M = 10.0 m

retical distribution is also indicated in Figure 11. The total number of events was 2113 and the theoretical number at the mean is 123.8.

Similar calculations were carried out for the other slices as well. The results are shown in Figure 12. Standard mean values were plotted and straight line best fit was found to be $W_{MEAN} = 11.44 + 1.197\ B_M$ in tonnes. Standard deviations are also plotted. They seem to grow up to about 15.0 m, then tend to decline; consequently, straight line of best fit could not be applied. The best curve fit was found to be $\delta = .98B_M - .023B_M^2$. Figure 12 also indicates that the sum of calculated standard mean and 3.5 times standard deviation is a reasonably good approximation to the MOL curve. Ultimate limit states provisions in the Ontairo Bridge Design Code are based on a safety index $\beta = 3.5$. Thus, it can be concluded that the MOL Curve that was selected as an upper bound to the population of vehicles is also statistically satisfactory.

According to Miner's theory, fatigue damage in steel is directly proportional to the number of stress events and to the third power of the stress proper. Figure 13 illustrates the distribution, that had been shown earlier in Figure 11, upgraded by multiplying the number of events with W^3. This can be referred to as Miner's distribution. It can be seen that Miner's mean has shifted to the right — its value is 28.91 tonnes, while the standard deviation has somewhat decreased to 6.19 tonnes. The Gaussian curve has a close fit to the distribution.

Similar calculations were carried out for the other

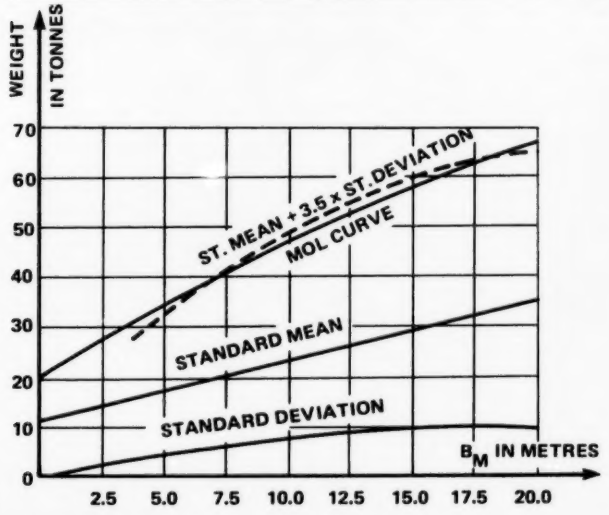


Figure 12/ Relationship Between MOL and Standard Mean

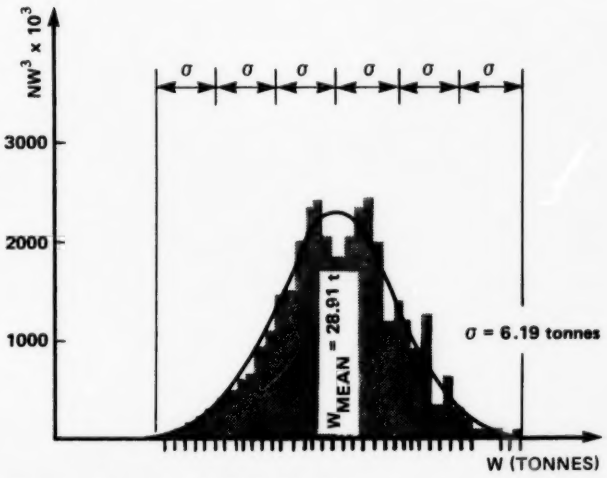


Figure 13/ Miner's Distribution for $B_M = 10.0$ m

distribution curves at ΔB_M = 2.5 m intervals. The results are plotted in Figure 14 along with a straight line fit $W_M = 12.30 + 1.60B_M$ in tonnes. Shown also is the MOL curve in comparison with three factored versions of the Miner's mean. It appears that the factor 0.625 is the most appropriate and it is suggested that it replace the present value of 0.800 in the Ontario Bridge Design Code. In the past, fatigue failures occurred in the Province of Ontario rather infrequently and the cause, without exception, has been identified as improper detailing and/or faulty construction. The present load factor of 0.800 is rather conservative in light of these calculations and the fact that structural overdesign does not necessarily prevent fatigue failures.

The availability of a Miner's mean can also help in establishing procedures in conjunction with cyclic and shake-down testing for research and development work in addition to future evaluation of existing bridges. This entails defining the ratio between serviceability limit states Type I and ultimate limit states. Demand for strength at ultimate limit states can be determined in terms of the MOL curve such that U = KαD [MOL]

where:

U = strength at ultimate limit states
K = constant
α = load factor
D = dynamic allowance

In accordance with the 1979 edition of the Ontario Bridge Design Code, α = 1.40 and, for most bridges under a single truck loading, D = 1.45. Consequently:

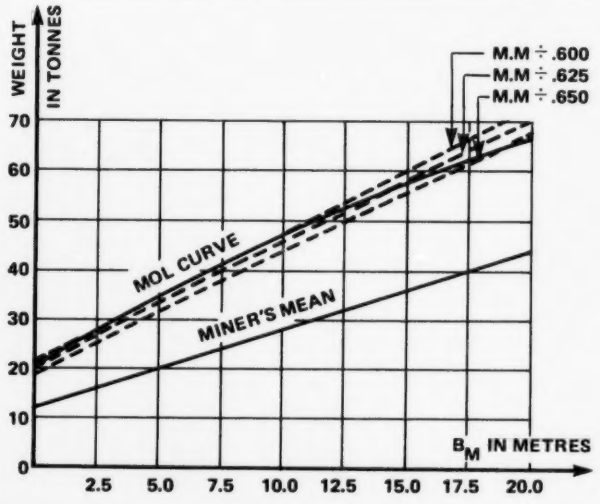


Figure 14/ Relationship Between MOL and Miner's Mean

$$U = K \cdot 1.40 \cdot 1.45 \cdot [MOL] = 2.03K[MOL]$$

Load level at serviceability limit states Type I can be expressed in similar terms using the results presented in Figure 14:

SI = .625 K [MOL] and the ratio sought:

R = SI/U = .308

In other words, in order to satisfy the present Code, cyclic and shake-down tests are to be carried out at about 31% of ultimate strength level for the number of repetitions specified in Section 11 for various classes of bridges. If dead load consumes a considerable part of ultimate strength, as it does especially for larger bridges, its factored load effect should be added to the expression of U above. The net result is that the cyclic load level is further reduced by the presence of dead load.

If one wishes to carry out accelerated tests in order to reduce the number of cycles applied, it can be done as follows:

$$N_a = N_c [f_c/f_a]^3$$

where

N_a = number of cycles in accelerated test
N_c = number of cycles specified by the Code
f_c = cyclic stress level established above
f_a = accelerated test level

It would be, however, proper to limit the accelerated stress level in terms of loading to 2.0δ (standard deviation to Miner's mean). It is not shown in this paper, but the average δ value was found to be 6.75 tonnes in the 1975 survey.

5/Conclusions

1/ The 1979 truck survey was a rather inexpensive operation and its results have only a limited value.

2/ There have been 19 vehicles, carrying heavy machinery and raw forest products, violating the MOL curve. Means should be explored by which such violations are discouraged in the future.

3/ Load factor for serviceability limit states Type I may be reduced from 0.800 to 0.625 in the Ontario Bridge Design Code.

4/ Miner's mean can be used to establish stress levels for fatigue and shake-down testing for research and development work.

6/ References

1/ **"The Highway Traffic Act"** by the Government of Ontario. January 1979, Toronto, Ontario.

2/ **"Standard Specifications for Highway Bridges"**, The American Association of State Highway and Transportation Officials, 1977, Washington, D.C..

3/ **"Truck Weights and Bridge Design Loads in Canada"** by P.F. Csagoly and R.A. Dorton, Ministry of Transportation and Communications, Ontario, 1978.

4/ **"The 1975 Ontario Truck Survey"** by A. Agarwal, P. Csagoly and M. Wolkowicz, Ministry of Transportation and Communications, Ontario, 1977.